Annex 6: The effect of environmental changes in the Galician sardine fishery

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Abstract

The highest catches of the Iberian sardine stock are taken from the southern part of Galician waters (NW corner of the Iberian Peninsula) and northern Portugal. Landings are mainly composed of younger fish, which reflects the proximity of the main recruitment area to the fishery grounds.

Since 1978 there has been an improvement in the knowledge of the biology and stock dynamics of sardine around the Atlantic Iberian waters. In the last decade a consecutive years with poor recruitments result in a depletion of stock below limits previously recorded. The recruitment processes seem to be driven by oceanographic (local) and climatic (global) events, this dependence on both phenomena may explain the fluctuations on the landings in the sardine fisheries in Atlantic Iberian waters.

Given the dependence of the fishery in this area on the strength of the recruitment, different relationship between biotic components (spawning stock size, recruitment, landings and recruitment landings) and abiotic: climatic indices (NAO-winter, Gulf Stream and AMO) and local oceanographic coastal events (upwelling and poleward current) were analysed.

In the analysis of the abiotic series in the period (1978–2005), there appears to be a shift in the general trend in 1995. In addition at the end of the nineties several consecutive years with poor recruitment result in a depletion of the stock below limits previously recorded as well as changes in the distribution area. Before the shift was observed the recruitment variability could be explain by the environmental variables, but since then the correlation is poor.

INTRODUCTION

Iberian sardine, as with most of the clupeoid fish species, occurs in highly dynamic areas in which turbulence regimes are predominant. Turbulence is important because it acts on the advention/retention larval mechanisms and larval-prey encounter rate that ultimately affects recruitment success and eventually the fishery (Cole and McGlade, 1998; Lasker, 1975; Cury and Roy, 1989; Bakun, 1996; MacKenzie, 2000). The occurrence of synchronous events, i.e. either depletion or increase in clupeoids fish species such as anchovies or sardines, over large geographically separated areas has been widely reported, which suggest large-scale climate forcing (Lluch-Belda *et al.*, 1989; Swartzlose *et al.*, 1999). In addition to large-scale forcing, there might be local events such as coastal upwelling or low-range thermohaline currents which can largely contribute to recruitment variability.

The highest catches of the Iberian sardine stock (*Sardina pilchardus,* Walb) are taken from the southern part of Galician waters (NW corner of the Iberian Peninsula) and northern Portugal (Fig. 1). Actual knowledge of this stock states that the bulk of the recruitment at age 0 occurs off the northern coast of Portugal (Anon, 2000; Porteiro and Pestana, 1997) from June-October while the spawning period is October-May (Re *et al.*, 1990; Solá *et al.*, 1990). Spawning occurs in two main areas, off the Atlantic coast of Portugal with a marked peak in winter and in the Cantabrian Sea which peaks in spring. Although Galician waters are outside these main spawning areas and only the southern part of this region is in the vicinity of the main recruitment area, sardine landings in Galicia are important, especially in the middle of the year, suggesting a feeding movement or migration (Carrera and Porteiro, 2002). According to Porteiro *et al.* (1986) there is an age gradient pattern from the Spanish/Portuguese border where most of the fish are younger to the Cantabrian Sea where the bulk of the population are older. This and the lack of juvenile fish in the Cantabrian Sea were also observed in earlier investigations (Fernández and Navarro, 1952).

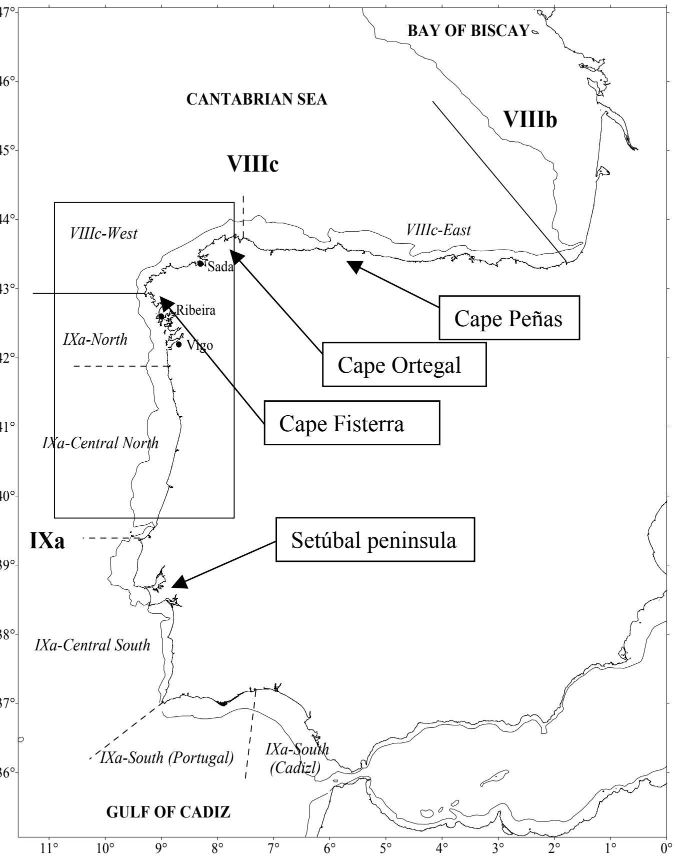

Figure 1: Iberian Peninsula showing the ICES Sub-Division and the sardine main fishery ground surrounded by a box. South Galicia is in IXa North area.

The sardine fishery off south Galicia distinguishes two different market categories. One of the categories is composed by younger fish, termed *xouba*. It achieves high price and mainly occurs between the end of spring and beginning fall, the other category is the adult sardine, mainly <21 cm length (i.e. younger than 4 years). *Xouba* category in south Galicia (i.e. 0 and 1 year classes) represents up to 48% of the total landings in numbers averaged for the period 1978–99. In some years their contribution reaches up to 93% of the total number of fish caught. However, there were also periods of low contribution, especially 1985 in which younger fish only represented 5% of the total. The variation in the relative contribution of this fish category seems to be affected by the strength of the incoming year class. The main fishery occurs in or close to the recruitment areas and the time-series of landings by areas shows important fluctuations. In addition, since 1985 there is a declining trend in the catches in both North Portugal and South Galicia (especially in the latter), achieving the lowest yield of the time-series in the most recent years.

Off the Galician coast, two different wind regimes occur: winter (October-March) and summer (April-September). The winter regime is dominated by southwesterly winds and the summer regime by northwesterly winds. The winter winds contribute to develop a poleward current along the inner shelf. (Frouin *et al*., 1990). This current with higher salinity and warmer water but relative poor nutrient contents is located at some distance from the coast, due to the inertial and centrifugal forces and by the presence of the Setubal peninsula. Close to Finisterre Cape this current is located close to the coast and being further deflected by Cape Ortegal when progressing through the Cantabrian Sea, but it turns close to the coast again after Cape Peñas. In the area between Cape Finisterre and Cape Peñas, an inner shore counter-current movement is thus created, which may function as a retention area for eggs, larvae and early juveniles. When south/south-westerly winds are more intense, this poleward current may prolong itself onto the Cantabrian Sea, close to the coast, and may reach even the French shelf. Under a situation of dominant north-quadrant winds (i.e. the typical summer situation), the whole west coast is dominated by upwelling events (Wooster *et al.*, 1976; Blanton *et al.*, 1984). The poleward current disappears, and it is replaced by an equatorward current close to the shore. The equatorward current starts from the area of Cape Peñas, and moves through Cape Finisterre and along the Portuguese west coast. This current is deflected by Cape Peñas, Cape Ortegal and Cape Finisterre, creating counter-currents downstream, which could act as retention areas.

Distribution area

The Iberian sardine is distributed along the whole continental platform of the Iberian Peninsula. It is mostly distributed close to the coast, not exceeding the depths of 200 m. The juveniles are generally separated from the adults, closer inshore, and associated to the river mouths and the "Rias".

Spawning areas and seasons

The sardine has three main spawning areas: One in North-Western Portugal, a second in the South Coast of Portugal-Gulf of Cadiz, and another in the Cantabrian Sea.

Spawning season is spread from the start of autumn to the end of summer. The peak spawning is different in the three areas:

Cantabrian Sea: April-May;

Portuguese West Coast: January;

Portuguese South Coast-Gulf of Cadiz: December-January;

Distribution and migration of juveniles and adults

In winter, the eggs laid along the Portuguese coast are transported Northwards in the South-North circulation which is present in the winter period.

In spring, eggs and larvae from the Cantabrian Sea are transported by the currents to the West, to the area of Galicia. In the area there is a more or less permanent gyre, which functions as a retention mechanism for the eggs and larvae in the area. In years when there is a strong upwelling in this area, the eggs and larvae will be transported offshore, and lost to the system. In the years when there is a circulation North-South, the larvae are carried along to the West coast area, rich by the upwelling. When this circulation does not exist, there is instead a global South-North circulation, leading to loss of the larvae/juveniles from the coastal system.

The juveniles concentrate themselves in the area of the "Rias Baixas" from May to September. They also concentrate themselves in sheltered places along the Portuguese coast. By the end of the year (November-December) the juveniles are also spread all along the Portuguese coast.

All conditions which lead to enrichment of the coastal area, and retention of the larvae/juveniles in this area, will contribute to the success of recruitment.

In years when there is important abundance in the Cantabrian Sea, the Cantabrian is dominated by the adults. It has been observed that the age composition is shifted towards older ages as one moves from the South to the North. In "normal" years, the fish along the Portuguese coast include in general fish up to 6 years old, while the sardine in the Cantabrian Sea are mostly older fish, up to age 12.

In these same years, the South coast area was dominated especially by small sardines,

Food and feeding of the different life stages

Sardine are filter-feeders (passive filter-feeders). The evidence presently available indicates that they are opportunistic feeders, and will eat both phytoplankton (with a preference or exclusivity on diatoms) and zooplankton. There have been some years when the condition factor of sardine was significantly lower than in the other years.

Link to environmental conditions

The link between climate, oceanography, the structure of the ecosystem and pelagic fish in the N Atlantic Iberian waters can be formulated as a conceptual model in which alternative modes of the climatic system lead to divergent oceanographic conditions and in turn to the dominance of alternative plankton and fish species.

On one side, dominance of boreal climatic modes, as those indicated by positive NAO and the influence of northern winds and pressure anomalies is associated to increased turbulence in the surface ocean, relatively low water temperature and high average upwelling intensity. Such conditions favour phytoplankton productivity during upwelling-induced blooms and small copepod species (e.g. Acartia) that are able to track the food increase at short time-scales. In turn, the abundance of small copepods and phytoplankton can be used efficiently by sardines through filter-feeding.

On the other side, a growing influence of subtropical climatic components, as indicated by EA, would increase water surface temperature and the stratification of the surface layer, while average upwelling intensity and frequency decrease. Phytoplankton productivity would decrease because of the reduced nutrient inputs, but changes in the dominance of species (i.e. dinoflagellates versus diatoms) or local blooms caused by changes in currents may lead to increases in biomass (Richardson and Schoeman, 2004).

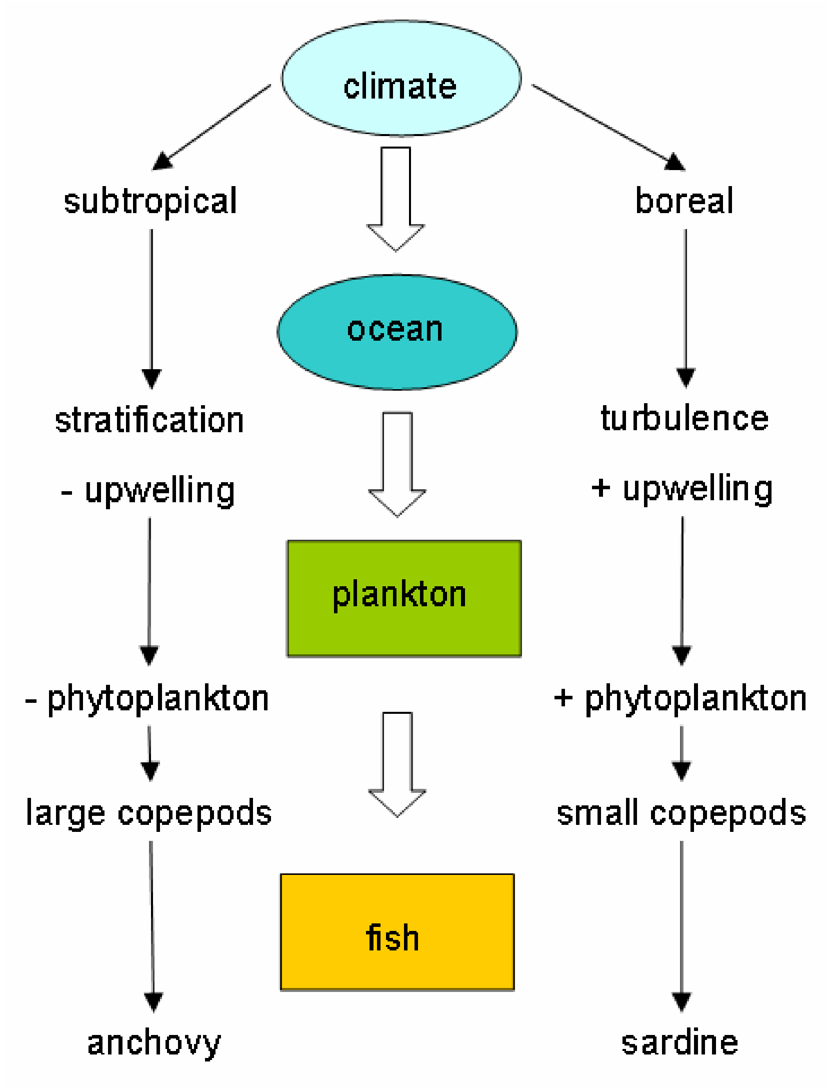

Fig. 2. Conceptual model in which alternative modes of the climatic system From: ICES/GLOBEC Workshop on Long-term variability in SW Europe. Lisbon, 12–16 Feb. 2007.

The reduced upwelling would be a positive factor for anchovy recruitment and large copepods which are able to feed on relatively large phytoplankton, as some dinoflagellates. Also, adult anchovies would find food of appropriate size for sustaining the population and producing large reproductive outputs.

The conceptual model describes the average multiannual dynamics in the main climatic, oceanographic and ecological features in the study region. Also, the terms reduced upwelling or increased stratification must be taken in relative value, as upwelling events never ceased completely in the region.

Regime shifts. The underlying causes of the described variability may also change during the observational period. This is suggested by the match and mismatch of positive and negative anomaly periods when comparing indices. Sudden changes in most series are generally associated to shifts in the oceanographic and ecosystem regimes (e.g. De Young *et al.*, 2004). Similar shifts were recognized in most upwelling regions (Borges *et al.*, 2003, Chavez *et al.*, 2003, Alheit and Ñiquen, 2004, Cury and Shannon, 2004). Large changes in climate related to El Niño-Southern Oscillation (ENSO) were often claimed as one of the major underlying causes of ecosystem shift, mainly in the Pacific (e.g. Chavez *et al.*, 2003) but it also can affect other oceans because of climatic teleconnections (Barnston and Lievezey, 1987). Major changes in the ecosystems of the NE Atlantic have been described for the period between late 1970s and 1990, but the exact timing of the shift varied among the target variables (Beaugrand, 2004, Edwards and Richardson, 2004, Richardson and Schoeman, 2004). Climate effects, as the change in wind speed and direction in the late 1970s, may need a different time to integrate as a clear response in some biological compartments. In this regard, plankton and short-living pelagic fish are among the first to show alterations, but the ability to identify the timing is also dependent of the statistics employed (Beaugrand, 2004). The shift in the late 1970s identified in this study is coincident with a major ENSO-related shift in the Pacific (Chavez *et al*., 2003, Alheit and Ñiquen, 2004) and it has been also indicated in zooplankton CPR data from the NE Atlantic (Dickson *et al*., 1988, Richardson and Schoeman, 2004). One major feature of the shift detected in the Iberian case is the coincidence of peak abundances of both sardine and anchovy species prior to 1975. Fishery data report a marked decrease in the distribution area of Iberian anchovy, formerly well distributed through the shelf (Junquera, 1984) but now restricted to major populations in the E Bay of Biscay and the Gulf of Cadiz (e.g. ICES 2005). In contrast, sardine populations have fluctuated in abundance but never abandoned the main distribution centres (ICES 2005, Carrera and Porteiro, 2003).

METHODS

Three different kinds of variables were used in the analysis, each of them as a time-series between 1978 and 2005. The variables are:

1) Fishery data:

- *landing*: annual landings from south Galicia as reported in Anon (2006)
- *xouba*: annual landings from Vigo harbour from this category
- *Ssb* Spawning stock biomass Anon (2006)
- *recruits*: estimated recruitment from the Iberoatlantic sardine assessment model (Anon, 2006)
- *recstrength*: is a categorical index estimated from the catch-at-age 0 in number obtained in south Galicia and north Portugal, i.e. main recruitment area The index for a given year has three values, -1 when the catches at age 0 of the precedent year were higher than the 3rd percentile of the whole time-series; 0 when the catches were between the first and the third percentile and 1 when the catches at age 0 of the precedent year were lower than the first percentile.

Large scale atmospheric and oceanographic events.

- *NAO index* (Hurrel, J.W., 1995). The index is split in two components;
- *NAOwinter*: Winter component (between December of the precedent year until March of the year in course) which coincides temporally with the main spawning time off Western Iberian Peninsula
- *NAOspring*: Spring component (from March to May), coincident with the main spawning time in the Cantabrian Sea.
- *Gulf* index: from Taylor (1996; http://www.pml.ac.uk/gulfstream/site), an annual index of the variability in the position of the Gulf Stream
- *AMO:* Atlantic multidecadal oscillation: http://web1.cdc.noaa.gov/Timeseries/AMO/

Local scale events

- *Iw*: Upwelling index computed for a point off the Galician coast using the atmospheric pressures (April-September) provided by the Spanish National Meteorological Institute (details are described in Lavin *et al*., 1991).
- *Tewinterupy*: Poleward current index (estimated from the Ekman transport between October and December of the preceding year).
- *SST* Sea surface temperature for 42ºn 10ºW. Sst (global) taken from Coads database and split in two periods Sst_w (Oct-March) and Sst_s (Apr-Sept).

The time-series was preliminary analysed by plots of the temporal trends of each of the variables used, as well as with quantile-quantile plots (qq-plots) of the distribution of the observed values in comparison with normally distributed simulated data to test for normality. Also a correlation matrix between all variables (Table 1) is used in the analysis to investigate the relationships between.

Table 1: Correlation matrix (values in red: significant correlation)

	Correlations (Tabla_Sardina) Marked correlations are significant at p < .05000 N=28 (Casewise deletion of missing data)												
All Cases: 78-05	RECRUIT.(*1000)	SSB (t)	LANDINGS (t)	Xouba Vigo (kg)	GULF_anual	NAO_w	NAO_mam	Iw	Tewinterupy	AMO	SST_Wint	SST_summ	SST
RECRUIT.(*1000)	1.00	0.02	0.33	0.70	-0.29	-0.06	-0.07	-0.02	-0.17	-0.24	-0.28	-0.34	-0.37
SSB (t)	0.02	1.00	0.76	0.23	0.12	0.09	0.00	0.24	-0.02	-0.56	-0.23	-0.43	-0.41
LANDINGS (t)	0.33	0.76	1.00	0.56	-0.23	-0.03	-0.13	0.32	0.16	-0.67	-0.29	-0.55	-0.52
Xouba Vigo (kg)	0.70	0.23	0.56	1.00	-0.24	0.02	-0.19	0.18	-0.03	-0.27	-0.35	-0.36	-0.42
GULF_anual	-0.29	0.12	-0.23	-0.24	1.00	0.44	0.00	-0.02	-0.11	-0.09	-0.26	0.13	-0.05
NAO_w	-0.06	0.09	-0.03	0.02	0.44	1.00	0.36	-0.02	-0.09	-0.03	-0.06	0.15	0.07
NAO_mam	-0.07	0.00	-0.13	-0.19	0.00	0.36	1.00	0.11	-0.18	-0.11	-0.13	-0.04	-0.10
Iw	-0.02	0.24	0.32	0.18	-0.02	-0.02	0.11	1.00	0.12	-0.31	-0.08	-0.53	-0.39
Tewinterupy	-0.17	-0.02	0.16	-0.03	-0.11	-0.09	-0.18	0.12	1.00	0.05	0.34	-0.14	0.09
AMO	-0.24	-0.56	-0.67	-0.27	-0.09	-0.03	-0.11	-0.31	0.05	1.00	0.43	0.59	0.62
SST_Wint	-0.28	-0.23	-0.29	-0.35	-0.26	-0.06	-0.13	-0.08	0.34	0.43	1.00	0.40	0.79
SST_summ	-0.34	-0.43	-0.55	-0.36	0.13	0.15	-0.04	-0.53	-0.14	0.59	0.40	1.00	0.88
SST	-0.37	-0.41	-0.52	-0.42	-0.05	0.07	-0.10	-0.39	0.09	0.62	0.79	0.88	1.00

Recruitment shows negative correlations with all oceanographic features. *NAOwinter* index shows significant correlation ($p<0.05$) with *GULF* and *NAOspring* indices. Winter events gave low correlations with recruitment. Large-scale events (NAO indices and Gulf) exhibited higher correlation between themselves than with local-scale indices (Upwelling and poleward current).

Younger sardines account for up to 70 % of the variability found in the total yield in south Galicia ($p<.0001$). Furthermore, a simple linear regression between *xouba* landings from Vigo and the predicted recruitment at age 0, as estimated in the assessment model of this unit stock (Anon 2006), was also significant and accounted for 56% of the variability in the *xouba* landings. The upwelling index is estimated from the Ekman transport during the period from April to September. The Ekman transport in that period is mainly produced by north /northwesterly winds, which are responsible for summer upwelling in the area. The Poleward current index is estimated from October to December of the previous year component of the Ekman transport. The Ekman transport on that period is produced by south/southwesterly winds, which causes among other oceanographic factors the poleward surface current known as the Navidad current (Frouin *et al.*, 1990). Thus, the two components of the Ekman transport (the winter and summer components) are used as indexes for the poleward current and upwelling intensity.

Once the preliminary analysis was completed, an empirical model of the recruitment, based upon standard multiple linear regression, was developed as a function of independent biological and physical variables.

$$\mathrm{Rec}_i = \beta_0 + \beta_1\,\mathrm{NAOwinter}_i + \beta_2\,\mathrm{NAOspring}_i + \beta_3\,\mathrm{GULF}_i + \beta_4\,\mathrm{Twinterupy}_i + \beta_5\,\mathrm{Iw}_i + \beta_6\,\mathrm{Recstrength}_i + \varepsilon_i$$

where the sub-index i is the year, $\beta = (\beta_0, \beta_1, \ldots, \beta_6)$ represent the parameter vector estimated by least squares in the fitting procedure, and ε_i are normally distributed errors.

Once the initial model was fitted to the data, a stepwise model selection procedure based on the Akaike Information Criterion (Sakamoto *et al.*, 1986) was carried out, in order to obtain the best possible model given the available covariates. This generic function calculates the Akaike information criterion for one or several fitted model objects for which a log-likelihood value can be obtained, according to the formula -2*log-likelihood + 2*npar, where npar represents the number of parameters in the fitted model. When comparing fitted objects, the smaller the AIC, the better the fit.

In spite the fitted model matched quite well with the predicted recruitment during the eighties, along the following years the discrepancies between them are in general higher.

Results and discussion

All covariates were retained on account the selection. For the period 1978–2000, the model is significant and accounts for 58% of the variability found in the recruitment. Figure 3 shows the predicted recruitment from the assessment model and the fitted model. In general terms, excluding 1985 and 1986, the model matches quite well with the predicted recruitment during the eighties. Nevertheless for the nineties the discrepancies are higher, and after that a successive years of bad recruitments results in a poor fit of the data.

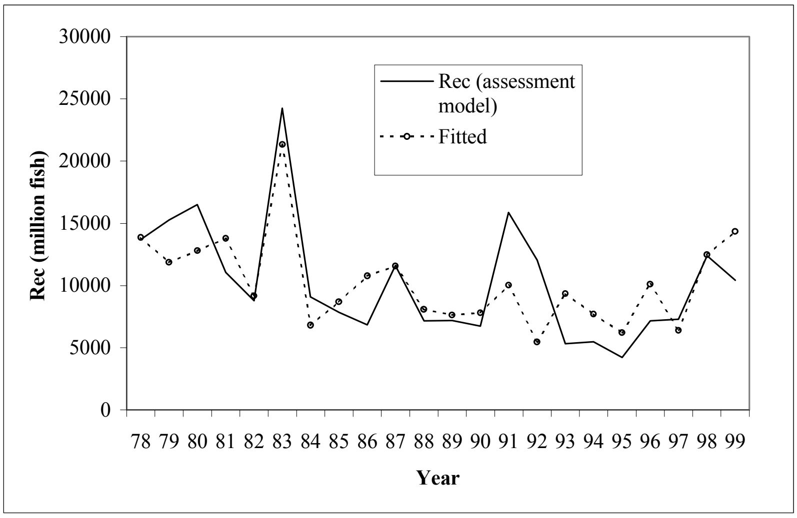

Figure 3: Predicted recruitment from the Assessment model as estimated in Anon (2001) and the fitted model (dotted line).

Regarding the partial effect of each variable on the overall mode, whereas the spring indices, Iw and NAO spring, and the GULF and the strength of poleward current had negative effect, the winter index, NAO winter had positive effect. On the other hand, the strength of the previous year has also positive effect.

The variability observed in the south Galicia sardine fishery is mainly driven by the strength of the incoming year class (i.e. recruitment at age 0). The results suggest that the recruitment of this fish species depends on both, large and local scale oceanographic events but also on the strength of the precedent year classes. The prevalence of younger fish in the same location as the recruitment seems to play an important role.

An increase in the spring indices (i.e. upwelling or NAO) seems to be related with an increase of the turbulence and in the advention processes. As stated by Cury and Roy (1989), higher turbulence is far from the optimal environment window.

On the other hand, recruitment process in sardine is the outcome of a wide space/time integral over different locations subjected to different regimes (from October to April in two main locations, western Portugal and the Cantabrian Sea). In addition, spawning grounds may change on account the size of the stock, as stated in Carrera and Porteiro (2003). In this context, changes in spawning area have recently been observed in this fish stock, which mainly affected the northern Portugal and Western Cantabrian Sea spawning grounds where the spawning area decreased.

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